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Design to Thrive

Optimising Residential Courtyard in Terms of Social and Environmental Performance for Ghadames Housing, Libya

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Abstract: Vernacular architecture comes from a wealth of knowledge and experience of humans who were able to adjust to the surroundings and adapt to even extreme climate conditions. In fact many old traditional settlements may fail to functionally provide high indoor quality according to the modern building standards. However, these buildings are still seen as a good example of serving the purpose of locals' social life and their ability to effectively respond to outdoor climate. Therefore, this work recognises the need to develop the courtyard concept to meet the social and environmental requirements of today's housing conditions taking the advantage of traditional architecture of Ghadames. The work carried out methods of descriptive and simulation analysis to investigate the environmental performance of existing and proposed residential courtyards employing natural ventilation system in terms of thermal comfort conditions. The optimisation process of the courtyard design not only relied on methods of observation but also householders and professionals' views were considered. Householders and professionals agreed that courtyard houses might be often linked to lower social classes but still serve most of social and climate purposes. The dynamic thermal simulation showed that indoor comfort temperature in a traditional courtyard was found to be at 34°C. An optimisation design process was conducted to a courtyard building resulted in reducing the indoor comfort temperature to about 28°C. Further results showed that the new design has improved the daylighting performance at 2.9% of average daylight factor. The work also outlined the applicability of using locally sourced building materials and their capacity to achieve high thermal performance particularly with reference to the use of organic date-palm fibre. It can conclude that the proposed design has integrated the passive climate design strategies to help achieving acceptable indoor comfort conditions and also sustainable features to further enhance locals' social life.

Keywords: Climatic design, EnergyPlus, courtyard house, indoor human comfort.

Introduction

Courtyard housings proved to be one of the best solutions in hot arid settlements and have been developed through experience of trial and error by local builders to serve social and cultural needs (Coch, 1998; Majid et al., 2012). Among a number of research group including Naciri (2012) and Nikpour et al. (2012) the role of the central courtyard in traditional architecture acting as a climate modifier was recognised and considered to be the best residential form in delivering sufficient natural ventilation and daylighting for interiors especially in hot regions. However, it has not been clearly identified in practice how such traditional techniques can be implemented in modern architecture (Bekleyen and Dalk, 2012).

The energy and environmental performance of courtyard buildings has been investigated and well documented in literature including Ben-Hamouche (2008), Al-Masri and Abu-Hijleh (2012) and Mandilawi (2012) who found that a great energy reduction of 54.25% can be achieved compares to conventional building forms. The abandonment of traditional wisdom and knowledge and the partiality of globalisation by many people to imitate western development and selection of inappropriate design and materials led to unsustainable and unaffordable constructions especially in developing countries (Bruen et al., 2014). Therefore, developing new forms of residence that take advantage of local context and new available technology will be the way forward to deal with social and environmental aspects as well as today's world challenges including energy and nature conservation issues.

Comfort and social needs are the main issues taken into account for optimising the residential courtyard of Ghadames housing and consequently its impact on total energy consumption. The internal centred courtyard is the most common type used in hot arid climate bringing many benefits including reduction in energy and noise, possibility of enhancing the indoor visual environment by opening windows into it and protection from outdoor harshness (Vaisman and Horvat, 2015). As reported in many studies including Abarkan (2000) and Nikpour et al. (2012) the courtyard in residential traditional architecture was an outcome of cultural as well as climatic aspects. However, the courtyard concept was developed and saw radical transformation by the 20th century in Libya as a result of life change and western culture influence (Bilghit 2007).

Research methodology

The research is carried out through methods of observation, interviews and dynamic simulation analysis. A case study of a traditional house was selected to investigate indoor thermal and design conditions of old settlements of Ghadames particularly the social and environmental role of central courtyard. The strategy was to conduct field surveys including temperature measurements during the interviews and simultaneously observe any phenomenal aspects. These aspects may be related to techniques used for ventilation, daylighting or occupants' behaviour supported by drawings, sketches and photos. EnergyPlus is used to first verify field data and test proposed courtyard performance.

The case study climate characteristics

Ghadames lies in the hot arid desert climate characterised with very low precipitation and far less than the potential evapotranspiration with large temperature swings in the daily cycle especially in summer resulting in low humidity rates. The city falls in the most extreme zones within the Libyan climates as located in the Sahara Desert region with almost eight months of hot and dry period and four moderate and partly cold winter period (Zifan, 2016).

Typical traditional house

Old settlements of Ghadames generally were designed to reduce exposure to outdoor conditions and enhance air movement through maximising shadings on buildings and street levels. The majority of traditional houses consist of three storeys and attached wall-to-wall from four sides creating very compact form. Streets and pathways are either fully or semi-shaded covered by first floor extended roofs. The form of the house combines high degree of compactness with minimum exposure to outdoor and relatively small plot area ranges

from 25 to 50 m². The space organisation of rooms varies according to the privacy level and functionality though. It is therefore constructed in three storeys to accommodate fully-sheltered ground floor consists of usually main entrance with stairs, guest room, storage and cesspit room. The first floor is a semi-private family area centralised by living-room which is surrounded by number of rooms.

The central hall is constructed in double-volume height with steps leading to mezzanine level which also consists of other private bedrooms. Stairs lead up to the roof level where kitchen is found as well as summer shed space used so often at summer nights. In Figure 1 the central living hall represents the inner courtyard of traditional houses which located in the heart of the house built in double ceiling height (4-5m). The 1m² roof aperture placed in the central living hall is the main source of daylight and natural ventilation for surrounding rooms. Hence, families spend most of their time in this hall and also practising many social and religious occasions.

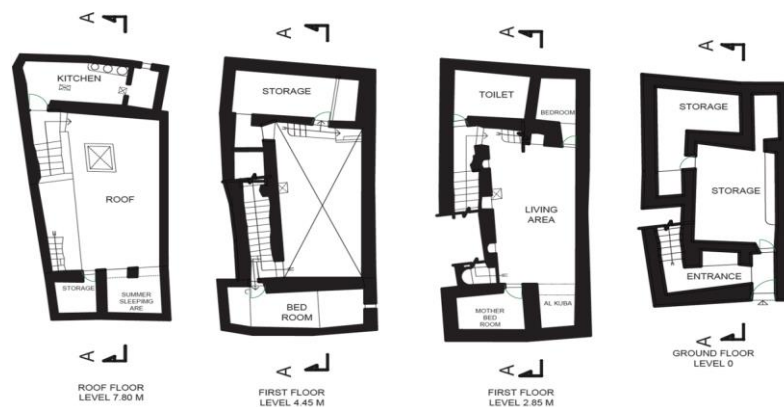


Figure 1. Plans of typical traditional house in the old town of Ghadames

Construction materials

Rocks and mud are the most common building materials in the old town of Ghadames settlements due to the nature of the desert land (Al-Zubaidi, 2002). Rocks are used in foundations and on ground floor for only the first 1.5m height. However, traditional houses constructed not only with sun-dried mud and stone which is mainly used in the bearing walls but also gypsum, limestone and wood are commonly used particularly in roof construction and finishing. Technically, walls are made out of sun-dries mud bricks with approximate digestions of 12×40× (75, 60 and 50) cm as shown in Figure 2.

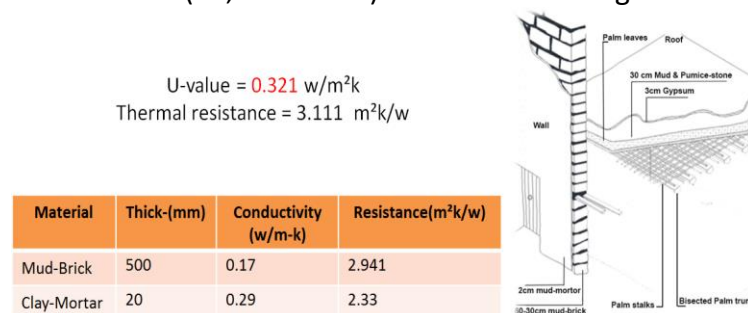


Figure 2. Local construction materials in traditional house

The thickness of the wall varies starting from 75cm on ground level to change at height of 3m to 60cm and then to 50cm at height of 5 to 6m (Al-Zubaidi, 2002; and Allafi, 2012). The size of bricks may slightly vary from building to another as Aalund (1983) stated that brick's size of 40×60mm, 40×50mm and 40×40mm is also found for ground floor, first

floor and top floor respectively. The mud bricks are made of a mixture of clay, gypsum and palm date fibre that all mixed up and burred underground for weeks before it is used.

Proposed prototype courtyard house

The proposed design of the courtyard considers various aspects including the climate, social needs and preference, use of land and shared resources, the urban complex and use of renewable energy sources. Figure 3 shows the layout of the ground floor consists of semi-public area for male visitors, semi-private area including the female guest room, kitchen and indoor covered courtyard space as well as semi-shaded carport and garage with a side family entrance. The first floor of the prototype house presents the private family area including inner balcony that overlooking the courtyard as well as summer shed space (loggia) which is used mainly in summer night as part of their tradition and climatic solution. The inner covered courtyard plays an important role in local community life and incorporating this space with elements like balconies, sittings, playground areas and fountain will enhance the quality and performance of entire home.



Figure 3. The proposed design of the courtyard in residential buildings

The courtyard has been moved from the centre as in traditional house to the side position and also from first to the ground floor to integrate certain natural elements includes vegetation and sittings. The courtyard ceiling height has been increased which also offers nice view from first floor balconies and further enhance thermal conditions. Clerestory skylights have been placed in the courtyard roof to enhance daylighting and also promote night ventilation strategy.

Construction materials

Local materials can be efficiently optimised and used in construction as approved to have high thermal performance including the dried-mud bricks, dry limestone sub-soil, and palm tree fibre as an insulation material. DesignBuilder has an editable library which is rich of construction materials and all thermal and physical variables including U-value, thermal and surface resistance, internal heat capacity and reflectance can be calculated. However, there are a number of studies investigated the use of organic materials especially if locally available as an alternative green materials, cheap, sustain longer, reproduced, reused or recycled. With the new technology dried-mud bricks have been developed to enhance its thermal and physical characteristics to achieve great time lag up to 10.5 hours compared to 6.7 hours for the concrete hollow blocks (Kamal, 2011).

In addition, Ghadames Oasis is rich in palm trees and thousands are found around traditional settlements. This type of plant has been under research by many studies testing the viability of its natural organic fibre to be used as an efficient and biodegradable

insulation materials (Al-Homoud, 2005; Khiari et al., 2010 and Agoudjil et al., 2011). More recent studies such as Lertwattanakruk and Suntijitto (2015) found that palm oil fibre is a great natural material to be used in industry to replace cement flat sheets to reduce thermal conductivity, optimise heat insulation and decrease its bulk density. Therefore, this study has considered date palm fibre for insulation materials as a green option as Table 1 shows.

Table 1. Wall construction materials in the proposed courtyard

| Ext | Material description | Thickness mm | Conductivity W/m deg. C | Density Kg/m ³ | Specific heat J(Kg deg. °C) |
|-----|--------------------------|---------------------------|----------------------------|---------------------------|--------------------------------|
| 1 | Dry limestone blocks | 25 | 1.26 | 1522 | 908 |
| 2 | Sun-dries mud-bricks | 150 | 1.8 | 1800 | 712 |
| 3 | Organic date palm fibres | 50 | 0.08 | 600 | 2000 |
| 4 | Sun-dries mud-bricks | 150 | 1.8 | 1800 | 712 |
| 5 | Gypsum board/mortar | 20 | 0.16 | 600 | 1000 |
| In | U-value | 0.211 W/ m ² K | | | |

Courtyard redesign and optimisation

Courtyard configuration

Throughout history the basic plan of a residential courtyard has been developed and modified to meet environmental and cultural aspects (Das, 2006). In this study the design concept and form of the courtyard in traditional housing was investigated and clearly noticed that the form and position of the courtyard plays an important role in modifying the indoor microclimate. Many in literature including (Amer, 2007) and (Heidari, 2010) found that rectangular deep courtyard form performs better for hot or desert climate. In desert climate such as Ghadames the protection of exposed surface of dwelling from intense solar heat and dusty hot winds are key aspects in optimising the courtyard which will have an impact on indoor thermal comfort as recommended by a number of researchers such as (Aldawoud, 2008).

However, there are more than variable have to be taken into account in optimising the environmental performance of inner residential courtyard including orientation, volume, position in relation to interiors. Muhaisen (2006) studied the optimum courtyard proportion (height and ratio) for different climatic zones and found that double ceiling height would determine the best thermal performance in hot arid climate. Hence, the courtyard geometry and proportion and level of exposure to outdoor conditions are considered in this study which will have a significant influence on indoor thermal conditions. However, the study uses a dynamic simulation programme *EnergyPluys* to investigate the performance of existing and optimised courtyard.

Simulation and findings

Traditional house

Simulation is run for typical summer week in July to compare results with actual temperature readings. The average of indoor thermal conditions is slightly higher than the temperature recorded in-situ but remains relatively constant. In Figure 4 comfort temperature (T_{op}) estimated around 34°C throughout the week inside the living room whilst actual temperature measurements were recorded at 29°C to 32°C. This can be interpreted as the microclimate of the old town has been modified by massive green fields and outdoor water surfaces contributed to humidify and drop down ambient air temperature which has not been accounted in the simulation. It is also the technique used to balance thermal indoor conditions during the day and night with aid of less exposure to sun as shown in

Figure 5. The total annual energy use inside the traditional house was found to be 28.87kWh/m² as this mainly consumed for lighting and hot domestic water. According to Noguera and Cervera (2012) Passivhaus specified that the annual total energy demand for space requirements should be limited to 20-30kWh/m².



Figure 4 Indoor thermal conditions predicted in the central hall of the traditional house

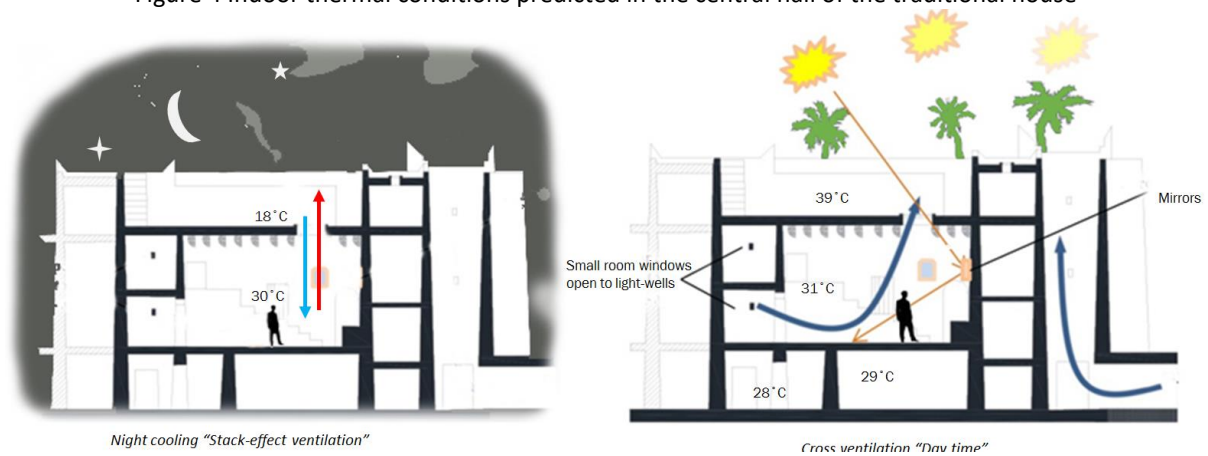


Figure 5 application of natural ventilation inside central courtyard in traditional houses

According to Samaan et al. (2016) EnergyPlus uses one of the best daylighting simulation programmes *Radiance* integrated into CIBSE and LEED calculations. In practice daylight factor of 2% to 5% showed to have a great balance between achieving good daylighting and thermal aspects (CSH, 2010). BREEAM daylight calculations indicate no compliance with minimum standards and the house fail to be adequately lit naturally. However, daylight average inside the central hall has been calculated at 1.21% and indicated poor daylighting distribution.

Table 2. Daylighting inside the central hall in DsdesignBuilder

| Zone | Block | Floor area (m2) | Min DF (%) | Uniformity ratio (Min / Avg) | Area adequately lit(m2) | Average DF |
|--------------|-------------|-----------------|------------|------------------------------|-------------------------|------------|
| Living-Room | first floor | 17.68 | 0.07 | 0.57 | 5.675 | 1.21 |
| Total | | 17.68 | | | | |

Proposed house

A typical summer week in July represents one of the hottest periods in Ghadames where temperatures reach 47°C during the day and drops down by 26°C at night. Indoor thermal conditions inside the courtyard were indicated to be far better due to the installation of skylight openings which enhance the night purge ventilation. The temperature was around 28°C with higher humidity rates than values found in traditional courtyard. In EnergyPlus external openings were set to be open at evening during summer

so only that night purge ventilation can take place at the specified time. This showed a significant impact on the heat balance inside the courtyard as can be seen in Figure 6. It indicates that indoor comfort temperature inside the courtyard is relatively constant throughout the typical summer week at 28°C in natural ventilation mode.

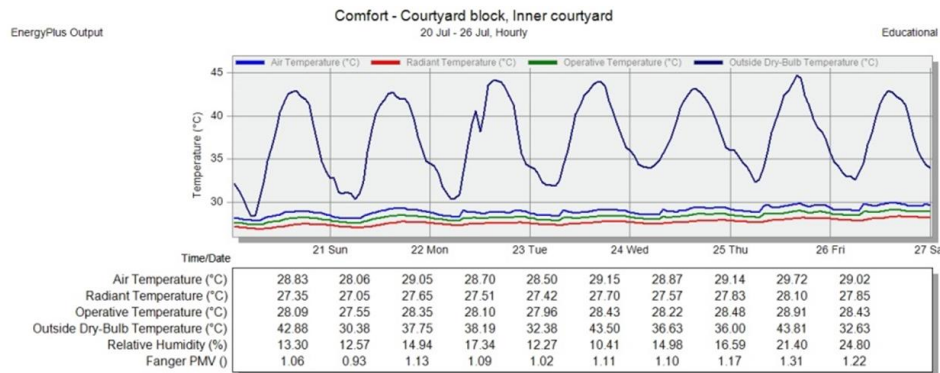


Figure 6. Indoor thermal conditions inside the proposed residential courtyard

However, to achieve the recommended human comfort temperature by ASHRAE 55 which is about 26°CAC was assumed to be on throughout the summer period from May to October at an average of 8 hours per day. As a result of that a 5.02kWh/m² is consumed for space cooling. According to the BREEAM rating the building did not fully achieved daylighting. However, with 15% window-to-wall ratio it is difficult to pass BREEAM credits but fairly can achieve acceptable performance especially in living spaces. In general, the house achieved good thermal performance with relatively good daylighting and the covered courtyard serves as solar room to deliver daylight deeper into interior spaces through skylights as Table 3 shows.

Table 3. Daylighting analysis inside the proposed courtyard

| Zone | Block | Floor area (m2) | Min DF (%) | Uniformity ratio (Min / Avg.) | Average DF | Area adequately lit(m2) |
|-----------------|-------|-----------------|------------|-------------------------------|------------|-------------------------|
| Inner balcony | FF | 3.960 | 0.57 | 0.40 | 1.4 | 1.300 |
| Living room | GF | 18.880 | 0.55 | 0.19 | 1.2 | 8.720 |
| Inner courtyard | GF | 29.250 | 0.70 | 0.24 | 2.9 | 21.320 |
| Total | | | | | | 31.340 |

Conclusion

This study highlighted the significance of both understanding the local architecture and context in designing residential buildings especially in extreme climates such as Sahara Desert. The courtyard in desert architecture has been and still considered to be one of the best options to meet residents' environmental and cultural requirements. Although, traditional architecture is proved to act responsively towards the environment where it stands but may not meet today's living standards. Therefore, this paper aimed to optimise the performance of residential courtyard to enhance the indoor conditions for Ghadames housing. The findings indicated that covered double ceiling height courtyard on the ground floor would have significant impact on enhancing indoor thermal and visual conditions. In addition, it creates a pleasant space for family and integration of natural elements such as water and vegetation would add great impact on indoor conditions. Installing skylights in the courtyard roof have resulted in improving the daylight and night stack ventilation. Local materials readily available found to have high thermal performance and reduce the construction cost which can replace all concrete and some other exported materials.

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